BINAURAL IMPROVEMENT IN NORMAL AND DEFECTIVE EARS IN A BACKGROUND OF OTHER VOICES

by

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SUMMARY PAGE

THE PROBLEM

To determine the contribution made by a below normal ear to the understanding of speech in a background of other voices.

FINDINGS

Monaural-defective subjects score 25 percentage points below normal on standardized tests constructed here for multiple voice interference effect. If amplification to the defective ear is provided, this loss is overcome.

APPLICATION

For physicians and personnel specialists recommending standards of hearing for various jobs throughout the Navy.

ADMINISTRATIVE INFORMATION

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ABSTRACT

A realistic artificial head with hi-fi microphones in the position of eardrums was placed in a large echo-free chamber, looking at a loudspeaker ten feet distant. The loudspeaker presented lists of ten colloquial sentences, while two other loudspeakers at $\pm 45°$ presented a male and a female voice reading interesting materials. Two-channel magnetic tape recordings were created of this "multiple-voice" situation, at various relative strengths of the background voices. These tapes were administered to one ear, and again to both ears, of 22 normal-hearing young men, and to 22 monaural hypacusics.* The monaural mode for the hypacusics was always the better ear. In the stereo mode, a hearing aid to the worse ear was simulated by separate amplification on that channel. The stereo mode was always superior in both listening groups, usually by about 25 percentage points in words correctly perceived. Four two-channel tapes in signal-to-noise steps of 2 decibels are offered to the oto-audiological clinic, standardized on 20 young normal men for the following purposes: (1) to specify exactly a patient's deficiency in understanding speech in multiple-voice situations, (2) to predict whether it would be worthwhile to recommend a binaural hearing aid fitting for a particular patient, and (3) to assess quantitatively what such a fitting actually contributed. These tapes are also useful for determining the performance of an individual in certain military multiple-voice listening situations.

**Hypacusic = an individual with defective hearing*

BINAURAL IMPROVEMENT IN NORMAL AND DEFECTIVE EARS IN A BACKGROUND OF OTHER VOICES

INTRODUCTION

In a previous paper[1] in this series, the effects of various modes of introducing speech into the two ears was investigated in normals and monaural hypacusics. Speech previously recorded from three persons successively was simultaneously led to three loudspeakers in a large echo-free room, all converging on two microphones 12 inches apart, connected to the two channels of the tape recorder. One loudspeaker 15 feet in front of the microphones transmitted a set of questions, the other two loudspeakers the same distance away but at ± 45°, transmitted prose of high interest. When the resulting two-channel tapes were played through loudspeakers (or earphones) and S was required to answer the questions from the middle talker, any of the binaural modes was usually, though not always, better than the better ear alone.

This result, with its consequences for listening in multiple-voice situations, as applied for example to hearing aid fitting (see Zelnick[2]), applied only to timing differences of the three voices at the two recording microphones. Furthermore, since the microphones were 12 inches apart, the timing differences were exaggerated as compared with the interaural timing differences engendered by the (somewhat smaller) human head.

For these reasons it was thought wise to repeat some of the conditions of interest in the first paper, but placing the microphones in the position of the eardrums of a realistic artificial head so that the acoustic differences at the microphones would incorporate (in addition to more realistic temporal cues), cues also of interaural intensity, timbre, spatial localization, etc. provided by the sound shadows of the head and pinnae.

Essentially the same equipment and procedures were used as in the prior study. The C.I.D.* Colloquial Sentences,[3] slightly revised[4] to equate sentence length, were used, which S was required to write down at an unhurried pace. Background voices were those of a man and a woman reading some quietly humorous essays of S. J. Perelman. On the first tape 20 sentences were recorded with the background voices at such a level that most of the 100 key words could be heard by normals; on a second tape 20 more sentences were recorded at 4 decibels (dB) lower relative intensity, and successive tapes likewise for a range of 12 dB in sentence/background ratio.

In recording this material the Shilling artificial head was used (for photograph see Rosen[5], Figure 2), a carved balsa wood core covered with a rubbery material to simulate the acoustic impedance of skin and flesh, fitted with 5/16 inch diameter meati 1.25 inches long and pinnae of the same rubbery

Originated at Central Institute for the Deaf material taken from an adult male by way of a plaster of Paris cast.

Normative data on speech reception at each of the four sentence/background ratios were determined with 22 young men aged 17-25, all with normal hearing ± 10 dB from 0.25-4 kiloHertz (kHz) (re ASA* 1951). Data were also provided for 22 patients who appeared at our audiologic clinic exhibiting one normal ear, the other with hearing loss from 16-55 dB (re ASA 1951 Standards, average from 0.5 through 3 kiloHertz (kHz) (See Appendix A)).

The first paper in this series showed no difference between loudspeaker and earphone listening at those modes of presentation in which direct comparisons could in fact be arranged with either type of transducer. Therefore in this second paper of the series, we abandoned the loudspeakers and simply placed earphones on the patient seated in a thoroughly sound-treated room and coupled the two-channel playback recorder to the earphones. The intensity of any ear was set at 30 dB louder than that at which the patient reported the tape sounded like human speech, though it was quite unintelligible.

For the normals, four listening modes were used: (1) Channel I to the preferred ear ("Monaural Mode"); (2) Channels I and II to preferred ear ("V-Cord Mode"); (3) Channel I to one ear, Channel II to the other ear (true "Stereo Mode"); and (4) both channels (suitably isolated electrically) to both ears ("Double V-Cord Mode"). Table I gives these norms and associated variances.

For the monaural hypacusis, four modes were used: (1) Monaural to the better ear; (2) Monaural to the worse ear; (3) Stereo Mode; and (4) V-Cord Mode to the worse ear. Table II gives the data for this group.

A first question to ask is whether the acoustics of the human head yields the same relative performances for the various modes as did the exaggerated temporal cues of the first study. To a first approximation this seems to be the case. The Principle of Blurring is corroborated, in that (1) the Monaural Mode is reduced at all levels when the second channel is added to that ear in the V-Cord Mode, and (2) when each ear receives a second channel (Double V-Cord Mode), performance is worse than the Stereo Mode at all levels. The Principle of Binaural Gain is partially corroborated, in that the Stereo Mode is always superior to the Monaural Mode and the Double V-Cord to the Monaural V-Cord Mode; but the Double V-Cord was not always superior to the Monaural Mode, as had earlier been the case.

For the defective group again the Principle of Blurring is found, in that the V-Cord Mode to the worse ear always degraded that ear's performance. The Principle of Binaural Gain is corroborated in that the Stereo Mode was up to 30 percentage points better than the performance of the Monaural Mode to the better ear.

**ASA - American Standards Association*

Table I. Intelligibility Scores on 22 Normal Young Man Using Four Listening Modes on Tests Differing by 4-DB Steps

Mode		Test 1 (S/N=0 DB)	Test 2 (S/N=-4 DB)	Test 3 (S/N=-8DB)	Test 4 (S/N=-12 DB)
Monaural	Mn	83.7	46.6	26.3	11.6
	Mdn	87.0	45.0	23.0	5.0
	SD	11.82	14.46	17.38	13.62
Double V-Cord	Mn	88.6	36.4	19.0	8.0
	Mdn	92.0	37.0	18.3	6.3
	SD	11.44	12.94	8.60	6.32
Stereo	Mn	92.2	66.7	48.5	23.0
	Mdn	92.3	67.0	51.0	21.0
	SD	7.00	10.84	17.28	15.18
Monaural V-Cord	Mn	79.4	30.3	16.4	9.2
	Mdn	80.0	30.0	11.0	6.0
	SD	11.44	11.26	12.78	8.74

Table II. Intelligibility Scores of 22 Monaural Hypacusics Using Four Listening Modes on Tests Differing by 4-DB Steps

Mode		Test 1 (S/N=0 DB)	Test 2 (S/N=-4 DB)	Test 3 (S/N=-8 DB)	Test 4 (S/N=-12 DB)
Monaural (Better ear)	Mn	87.5	45.6	29.3	17.1
	Mdn	86.0	38.0	22.0	12.5
	SD	15.04	19.20	23.04	12.88
Monaural (Worse ear)	Mn	71.5	29.8	16.2	8.7
	Mdn	82.0	22.0	10.0	7.4
	SD	25.5	31.10	14.08	9.84
Stereo	Mn	91.5	71.5	53.4	34.0
	Mdn	98.0	72.5	54.0	36.0
	SD	13.72	20.44	26.30	19.08
V-Cord to Worse Ear	Mn	52.2	16.5	8.4	5.6
	Mdn	54.0	12.0	7.4	0.0
	SD	25.80	19.90	9.92	7.60

The Stereo Mode contains the possibility for two opposing principles simultaneously, Binaural Gain in that a second ear is added, and Degradation, in that the second ear if defective may somewhat garble the message. In the present data, the Stereo is always the most superior Mode, but the Binaural Gain may still have been somewhat reduced by degradation. In this material we did not, as in the previous paper, set up the control condition needed (V-Cord to Better Ear Mode) to check on the Principle of Degradation.

These results allow us to offer the clinician an objective test of a patient's ability to understand speech in a babble of voices. Diminished ability in this regard is of course one of the commonest complaints in the otologists' practice, yet no way exists at present to check the patient's subjective impression. If the otologist's regime should result in an improvement in receiving speech when masked by other voices, the extent of such improvement cannot well be assessed. Furthermore, the usual formulae to express percentage of binaural hearing loss are quite arbitrary and are not based upon quantitative estimates of binaural defect for handling speech in one of the most usual social everyday situations. The suggestion here is that fairly simple taped tests will quantify this particular defect, allow one to assess improvements, and provide one research tool for investigating the factor of binaural hearing in general.

Four separate tests are hereby provided incorporating ranges of difficulty from "easy" to "hard". The average scores of 20 young ears for each of these tests in both the Monaural and Stereo Modes are in Table III.* Three suggested uses of these tests are found in Appendix B.

Table III. Intelligibility Scores of 20 Normal Young Men on Four Tapes, Differing in 2-DB Steps, Suggested for the Oto-Audiological Clinic

Listening Mode Monaural	Mean	Score At The 25th Percentile
Test A	93.9	92
Test B	86.3	78
Test C	59.2	45
Test D	38.1	25
Stereo		
Test A	98.7	96
Test B	98.5	98
Test C	92.8	91
Test D	84.1	78

**We are grateful to Miss Cynthia Angermeier, University of Connecticut, for collecting these data.*

SUMMARY

Two-channel tape recordings of the "multiple-voice effect" were created using a separate loudspeaker for each of three simultaneously presented voices in an anechoic chamber, and microphones in the position of the ear-drums in an artificial head. When one of these tapes is played through the usual home hi-fi stereo tape deck to two earphones, the stereo illusion is created so that the three voices seem to come from three points in space, one voice (to which the patient must respond) coming from directly in front. Background voices were raised relative to the signal voice, so that a range of 12 dB in Signal/Noise ratio was achieved. On 22 monaural hypacusics, in whom the loss in the defective ear was compensated for by separate amplification (simulating a hearing aid), the Stereo Listening Mode was always superior to listening with the better ear. On Tests 2 and 3, for example, the Stereo Mode yielded a gain of about 25 percentage points over the case of the better ear alone. Comparisons of these Listening Modes, and with 22 normal-hearing subjects as well, showed that the Stereo Mode uniformly leads to better intelligibility, (according to the Principle of Binaural Gain, as enunciated in the first paper of this series), but to an ear may degrade intelligibility. Four tapes are offered to the oto-audiologic clinic, with notes as to how they may be used: (1) to specify exactly a patient's deficiency in reception of speech-masked speech, (2) to predict whether it would be worthwhile in this regard to recommend a binaural hearing aid fitting, and (3) to assess quantitatively the contribution of such a fitting.

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Appendix A. Audiograms (ASA, 1951) of Monaural Hypacusic Subjects

Subject	Ear	Air or Bone C.	250	500	1000	1500	2000	3000	4000	6000	8000
CAH	R	AC	55	50	55	-	45	45	40	40	40
	R	BC	15	12	20	-	10	10	10	12	10
	L	AC	25	20	15	-	15	20	15	50	30
DGG	R	AC	15	10	10	-	10	10	20	20	15
	L	AC	35	30	30	-	35	25	45	60	70
	L	BC	15	10	5	-	0	10	10	20	30
KGM	R	AC	0	0	0	0	0	0	0	5	0
	L	AC	40	40	40	25	0	5	15	0	0
	L	BC	NR	NR	50	35	15	20	25	15	5
SCA	R	AC	5	10	5	-	5	10	15	20	20
	L	AC	45	40	40	-	20	60	60	65	55
	L	BC	22	20	20	-	15	30	40	-	-
RAL	R	AC	30	30	30	-	35	40	35	45	55
	R	BC	32	0	0	-	5	15	10	-	-
	L	AC	10	10	10	-	10	10	10	10	15
LDL	R	AC	10	10	5	-	15	20	65	25	45
	L	AC	30	35	40	-	70	75	85	NR	NR
	L	BC	20	30	30	-	45	50	NR	-	-
TWS	R	AC	10	5	5	0	0	10	15	15	15
	L	AC	30	30	40	50	55	60	60	60	55
	L	BC	5	0	10	10	10	20	20	20	15
DLW	R	AC	-	35	40	35	35	30	40	30	35
	R	BC	-	10	15	10	5	5	10	-	-
	L	AC	-	5	5	0	0	5	10	10	5
RBW	R	AC	30	35	35	45	25	20	20	35	25
	L	AC	5	10	5	20	20	15	10	55	20
WTH	R	AC	-	5	10	10	5	15	15	15	0
	L	AC	-	0	15	25	35	60	70	80	80

Appendix A. Audiograms (ASA, 1951) of Monaural Hypacusic Subjects (Cont)

Subject	Ear	Air or Bone C.	250	500	1000	1500	2000	3000	4000	6000	8000
DMN	R	AC	20	20	25	25	25	65	70	95	60
	L	AC	5	10	10	10	15	10	10	15	5
GST	R	AC	30	30	25	-	25	35	40	65	60
	L	AC	5	0	0	-	0	0	0	10	0
MAN	R	AC	30	20	25	20	15	40	45	55	60
	L	AC	10	15	0	0	0	10	20	20	15
CEH	R	AC	0	0	0	0	5	10	10	10	0
	L	AC	0	15	60	60	60	60	40	25	10
GFO	R	AC	5	10	10	-	5	15	35	75	NR
	L	AC	55	50	45	-	25	45	65	NR	NR
	L	BC	30	45	40	-	25	40	NR	-	NR
VPL	R	AC	5	15	15	10	10	25	25	20	20
	L	AC	30	55	30	20	10	20	15	15	45
	L	BC	25	45	20	15	5	10	20	15	15
ESL	R	AC	-	5	10	15	5	15	0	15	20
	L	AC	-	15	25	45	40	70	50	35	15
BJD	R	AC	20	15	10	-	10	10	20	20	0
	L	AC	25	20	25	-	30	35	50	55	70
MJO	R	AC	10	10	15	-	10	10	25	40	15
	L	AC	30	35	40	-	40	45	60	60	50
DEM	R	AC	20	25	25	-	25	45	45	50	55
	L	AC	15	10	5	-	5	10	15	35	40
RWK	R	AC	-	35	40	55	45	65	60	60	40
	L	AC	-	0	5	0	0	5	10	10	0
DRH	R	AC	20	20	25	-	10	20	25	30	20
	L	AC	5	5	10	-	5	5	15	15	10

Appendix B. Suggestions for Clinical Use of Tests A-D

A. <u>To Quantify a Patient's Ability to Understand One Person in a Background of Voices.</u>

On any reasonably hi-fi stereo tape playback the separate gain controls of the two channels are adjusted by the tester so that the 1-min calibration tones on the two tracks yield about equal loudness on the two earphones as established by a quick judgment on the part of the tester; this match is not very critical. The overall loudness is then set at a comfortable level for the patient by adjustment of the master gain control which governs both channels equally. The patient is then told to listen and simply repeat the sentences one by one to the tester, who scores with a checklist the key words correctly repeated as the test progress (See Appendix C for the sentences used).

If the patient had initially reported some difficulty with the cocktail party effect, the tester would start off with the easiest tape, Tape A, and progress if necessary to Tape C or even to Tape D until it became clear that for material on which normal ears had some difficulty the patient either had or had not a real problem in the Stereo Mode with multiple voices. If, for example, on Tape C in the Stereo Mode his score was 93% key words correct, he would be considered about average for this level of test difficulty (See Table III), but on Tape D his score in the Stereo Mode fell below 78%, he would be in the lowest quatrile of the normal group and could be considered to be well below average for more difficult material.

Figure 1 shows that the drop in intelligibility per dB of signal-to-noise ratio in the Monaural Mode is about 10%/dB, and it is likely that this is the order of magnitude also for the Stereo Mode. Therefore, if a patient scored, say, only 39% on Test D in the Stereo Mode, where 84.1% is normal, he could be considered as 4.5 dB below normal (84-39/10=4.5) in signal-to-noise ratio for that mode.

(The computation of intelligibility change in per cent per dB cannot be performed with the Stereo data in Figure 1 because the "ceiling effect" distorts the curve in the region of Tests A - C).

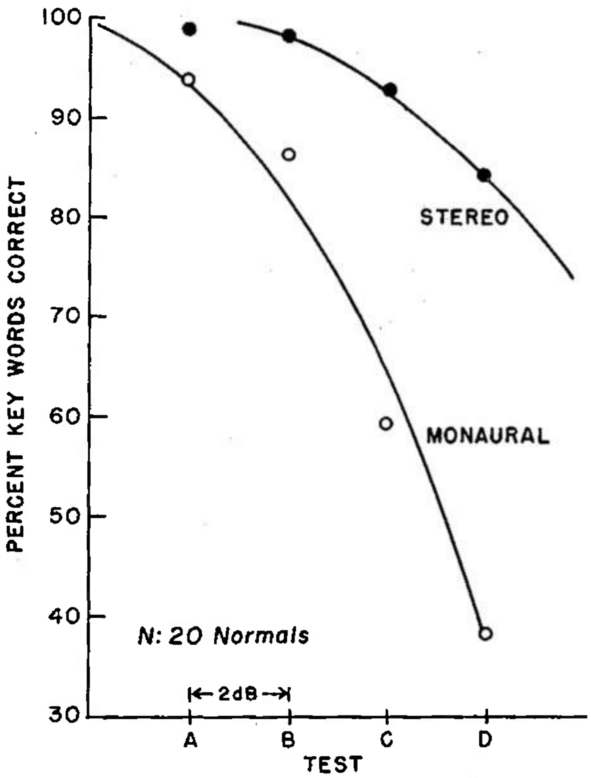

Fig. 1. Intelligibility in Normal Listeners of Multiple Voice Speech as a Function of Signal-To-Noise Ratio

B. To Predict Whether Binaural Aid Fitting Should Be Considered.

In this application the separate gain controls on the two-channel playback are utilized. The channel to the better ear is first set at comfortable loudness, and then the gain to the worse ear is increased until the patient reports approximately equal loudness in both earphones for the calibration tones. The extra gain on the worse side simulates the amplification of a binaural hearing aid. Of course, if both ears have symmetric hearing levels, this step can be skipped. Then the tester might compare the patient's performance with, say, Test C in the Monaural Mode to determine what the better ear can do alone in relation to the normal ear, then use Test D in the Stereo Mode. Just as no two patients are alike, so no specific pairing of Monaural-Stereo Modes can be standardized here; it is hoped that the ranges of difficulty of these tests will allow the tester to determine creatively the test pattern appropriate to each patient.

C. To Assess in dB the Effect of Binaural Hearing Aid Fitting.

It is possible that one phase of actual binaural hearing aid evaluation can be accomplished by this test, if a listening room with two fairly well-matched loudspeakers can be provided. The patient is seated with the loudspeakers a few feet away and placed symmetrically about ± 45° off midline; he responds to the tester's questions, first with and then without binaural fitting. The advantages of a second aid, if real, can be demonstrated quantitatively to tester and patient.

The especial virtue of these tapes for examining hearing aids in a free field is that all three voices come from each of the two loudspeakers, so that the full advantage of the head shadow is utilized in the stereo illusion. By contrast, in some speech-in-noise tests the speech comes from a loudspeaker on one side of the head while the competing signal comes from another loudspeaker on the other side of the head. In such a case, the result obviously depends greatly on whether the speech signal is directed toward the better ear, the noise from the second loudspeaker being reduced in that ear by reason of the head shadow, which would give a favorable S/N in the better ear, or whether the speech is directed toward the worse ear and thus shadowed from the better ear while the noise is relatively enhanced, which would give a very unfavorable S/N in the better ear. The present stereo test gives equal S/N at all times to both ears. This is not of course the condition in daily life, where voices are displayed in real space, but it does remove from the test conditions the variances of the head shadow associated with placement of hearing aids on the head, and renders more secure the comparison actually desired, namely, the monaural vs the stereo listening mode.

Appendex C. Lists of Sentences Used in this Study

List A

IT'S ONLY a FEW MINUTES ACROSS TOWN.

did YOU BRUSH YOUR TEETH this AFTERNOON?

i DON'T HAVE TIME to READ a MAGAZINE.

STREET CLEANERS are NOT very BUSY MEN.

WHY did they CALL the NEW ONE pretty?

is it WRONG to PARK UNDER the LIGHTS?

WOULD YOU LIKE to go FISHING TODAY?

IT'S TOO LATE to CHANGE the TIME NOW.

do YOU THINK I can BREAK the STRING?

ALL THESE LITTLE pieces ARE very HEAVY.

List B

PEOPLE DON'T go SWIMMING MUCH in the FALL.

YOUR JANITOR SHOULD KEEP it CLEAN.

I LIKE to WATCH the DENTIST pull TEETH.

List B (Cont)

THEY HAVE HAD ENOUGH of YOUR DRIVING.

APPLES are VERY GOOD THIS TIME of YEAR.

DON'T WATER the GRASS too MUCH.

CHILDREN DON'T BELIEVE in HIDING from TROUBLE.

EVERYONE SHOULD EXERCISE BEFORE BREAKFAST.

HAVE a COOKIE with YOUR COFFEE.

I'LL be AROUND OUT BACK of the HOUSE.

List C

SEND the OTHER BILL in my NAME.

CHILDREN who EAT GREEN APPLES are SORRY.

BE CAREFUL NOT to STAND in the WATER.

ARE you CHANGING the RIGHT of WAY HERE?

WOULD YOU LIKE SOME PIE for DESSERT?

COLORS on the PACKAGE WON'T TELL YOU ANYTHING.

CAN'T they MOVE the STREAM OVER THERE?

List C (Cont)

DO you LIKE EGGS EARLY in the MORNING?

TELEVISION is SPOILING the MOVIE BUSINESS.

MUSIC ALWAYS MAKES me FEEL HAPPY.

List D

YOU CAN FIND the KNIFE in the KITCHEN.

EATING CANDY BEFORE DINNER SPOILS one's APPETITE.

List D (Cont)

CATCH the PHONE WHEN it RINGS.

WHERE ARE you GOING WITH my FIVE-DOLLAR BILL?

don't SPEND ALL the CHANGE WHILE you're THERE.

MOVE the BED in FRONT of THAT WALL.

WHAT'S THAT LITTLE CUP doing OVER THERE?

THIS is the FIRST QUIET NIGHT we've HAD.

you CAN SEND your LETTER LATER.

DID you EAT THAT AWFUL CAKE?

Note: Only capitalized words are scored

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13. ABSTRACT

A realistic artificial head with hi-fi microphones in the positions of eardrums was placed in a large echo-free chamber, looking at a loudspeaker ten feet distant. The loudspeaker presented lists of ten colloquial sentences, while two other loudspeakers at $\pm 45°$ presented a male and a female voice reading interesting materials. Two-channel magnetic tape recordings were created of this "multiple voice" situation, at various relative strengths of the background voices. These tapes were administered to one ear, and again to both ears, of 22 normal-hearing young men, and to 22 monaural hypacusics. The monaural mode for the hypacusics was always the better ear. In the stereo mode, a hearing aid to the worse ear was simulated by separate amplification on that channel. The stereo mode was always superior in both listening groups, usually by about 25 percentage points in words correctly perceived. Four two-channel tapes in signal-to-noise steps of 2 decibels are offered to the oto-audiological clinic, standardized on 20 young normal men for the following purposes: (1) to specify exactly a patient's deficiency in understanding speech in multiple-voice situations, (2) to predict whether it would be worthwhile to recommend a binaural hearing aid fitting for a particular patient, and (3) to assess quantitatively what such a fitting actually contributed. This test is also useful for determining the performance of an individual in certain military multiple-voice listening situations.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
sentence intelligibility						
binaural speech reception						
multiple voice reception						
monaural/binaural comparisons						